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QUARTERLY PROGRESS REPORT

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Contract NASW-417

Bellcomm

QUARTERLY PROGRESS REPORT

July August September

1970

I. M. Ross
President

Bellcomm
955 L'Enfant Plaza North, S. W. Washington, D. C. 20024

Report No. 70-101-4
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QUARTERLY PROGRESS REPORT

ABSTRACT

The activities of Bellcomm during the quarter ending September 30, 1970 are summarized. Reference is made to reports and memoranda issued during this period covering particular technical studies.

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APOLLO/SATURN SYSTEMS ENGINEERING

Mission Planning

Mission Assignments

A draft issue of the Apollo Flight Mission Assignments (AFMA) document was prepared incorporating the latest program direction on the number of flights, the lunar landing site assignments for both Apollo 14 and Apollo 15, and the readjusted experiment assignments. A new format was introduced to incorporate most of the requirements in chart form. An interim revision to the October 1969 issue of AFMA was approved by the Associate Administrator identifying Hadley-Apennine as the approved landing site for Apollo 15.

Technical activities related to Apollo 14 and 15 included reviews of the Apollo 14 Mission Implementation Plan, the Mission Requirements documents for both missions, and a preliminary review of the Apollo 14 Flight Rules. A recommendation for a detailed objective on the new oxygen tank has been accepted for Apollo 14.

In preparation for the Apollo Site Selection Board meeting on September 24, a document was prepared (1) which focused the principal issues regarding the site selection for the Apollo 15, 16 and 17 missions. The accessibility, science value, landability and photography requirements of the various sites under consideration were discussed. The document was sent to all members of the Site Selection Board by the Apollo Program Director prior to the meeting and served as an outline for the meeting itself.

Analyses and background data were generated to brief the Apollo Program Director prior to a teleconference on lunar surface staytime duration for J-missions. An increase in J-mission staytime from 54 to 66 hours was approved.

Bellcomm assisted the Apollo Program Office in the preparation of Apollo Program Directive 55 which redefined experiments, detailed objectives and operational tests, while disapproving engineering tests as a classification.

Space Vehicle Performance

The Quarterly Weight and Performance Report dated July 1, 1970 was prepared and delivered. A recommendation to discontinue publication of this report was approved by the Apollo Program Director. Monthly weight and performance status

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(1) Apollo Site Selection Factors Document, Memorandum for File, W. G. Heffron, K. E. Martersteck, September 30, 1970.

presentations to the Apollo Program Director continued. Included in the July presentation was a discussion of Saturn V engine-out capability. (2)

The need for implementing concise and uniform reporting procedures for Lunar Roving Vehicle weight and performance status was identified. Alternative reporting methods and the Program's capability to perform weight analyses were evaluated to develop a method for the NASA Centers to use in monthly reports to the Apollo Program Office (APO). (3) A specific weight reporting procedure was approved for use in the monthly APO Weight and Performance reviews, and a format was submitted to MSFC for performance reporting. (4)

The H- and J-mission control weights were revised to reflect the modifications to the spacecraft that resulted from the Apollo 13 incident and, for the J-missions, to reflect revisions to the sites, schedule, and experiment assignments. Attention focused on the J-missions where present spacecraft actual weights, spacecraft control weights and performance limit weights are all very close. A recommendation that strict weight control be observed was accepted by the Apollo Program Director and is being promulgated with the revised control weights.

Preliminary results of a study on optimization of launch vehicle angle-of-attack were reported. (5) A trajectory optimized with an unconstrained angle-of-attack yields an idealized translunar payload capability about 5,000 pounds greater than a trajectory constrained to a zero angle-of-attack.

Mission Analysis

Mission Analysis studies for the Apollo 14 mission are in progress. These include assessing abort requirements and capability throughout the mission, manual translunar injection (TLI) backup, bootstrap photography coverage, and analysis of a minimum possible mission to better understand and define the criterion for committing to a TLI in the event of large launch vehicle dispersions during earth orbit insertion. A report was prepared on manual TLI backup. (6)

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(2) Saturn V Engine-Out Performance Capability, Memorandum for File, K. P. Klaasen, July 31, 1970.

(3) LRV Performance Status Reporting Methods, Memorandum for File, R. D. Raymond, August 6, 1970.

(4) LRV Weight and Performance Reporting, Memorandum for File, R. D. Raymond, P. F. Sennewald, J. C. Slaybaugh, August 31, 1970.

(5) Optimization of Launch Vehicle Angle-of-Attack by Steepest Descent Method, Memorandum for File, D. G. Estberg, July 28, 1970.

(6) Manual TLI in Apollo 14, Memorandum for File, D. R. Anselmo, W. G. Heffron, August 31, 1970.

An evaluation of the effect of the oxygen tank vent test during the transearth leg of the Apollo 14 mission has been made. The result shows that the effect of a vent done just after midcourse correction No. 5 (17 hours after leaving the moon), could result in errors of .04 degree entry flight path angle and about 5 nm entry position. This assumes no subsequent midcourse corrections. The errors incurred by venting just after midcourse correction No. 6 (the last one) are about .02 degree in entry angle and about 2.5 nm in position.

The subject of optimizing the overall probability of mission success by adjusting the Service Propulsion System (SPS) propellant loading and allowing the possibility of completing TLI with the SPS in event of an early S-IVB shutdown was pursued further this quarter. A memorandum which emphasized the general conclusions of the study as well as introducing some contingency considerations was issued. [7] It recommended that the SPS loading be determined primarily by balancing the margin over the propellant budget requirements against corresponding launch vehicle capability. Therefore, for missions having SPS margin over and above the budget and launch vehicle probability of TLI success less than 3σ, the SPS propellant margin should be reduced by an amount not to exceed; (a) that required to achieve 3σ launch vehicle performance, (b) that required to reach the value corresponding to theoretical maximum probability of mission success, or (c) that which reduces the SPS probability to 3σ.

In studying mission opportunities for the J-missions, lunar accessibility was examined in two ways: determination of the accessibility of specific sites each month, and determination of the area on the lunar surface which is accessible during a specific time period. For the winter period the accessible region is concentrated in the southeast. [8] Possible landing areas extend beyond 60 degrees east and to approximately 35 degrees south. The region of accessibility is quite small in the northwest and is essentially non-existent in the northeast. The area accessible in the summer is substantially larger than in the winter and extends to a peak southern latitude of about 34 degrees and to a peak northern latitude of about 46 degrees. The area accessible in the summer is about 100% greater than in the winter for the 1971-1972 time period. Documentation of the computer programs used for the determination of accessible areas was published. [9]

To support the J-mission site selection process, the performance requirements for the launch vehicle and the spacecraft were computed for missions to contending lunar landing sites on the J-mission schedule. This work demonstrated a slight performance advantage for Marius Hills over Hadley for the J-1 mission. The results also showed that both Descartes and Copernicus requirements would allow a

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(7) SPS Propellant Loading Philosophy, Memorandum for File, A. P. Boysen, Jr., K. E. Martersteck, August 13, 1970.

(8) J-Mission Lunar Accessibility During November and December 1971, Memorandum for File, R.A. Bass, July 7, 1970.

(9) Time Specific Apollo Lunar Surface Accessibility for Relaxed Free Return Missions - Computer Program Description, Memorandum for File, S. F. Caldwell, September 1, 1970.

mission to either of these two sites during the period from January through April of 1972. All five sites investigated, viz., Marius Hills, Descartes, Hadley, Copernicus, and Davy, are feasible for the mission in the summer of 1972.

Because of possible renewed scientific interest in a lunar mission to Tycho, performance requirements were examined for that site. It was found that missions using three-impulse lunar orbit insertion are feasible from January through March 1972 if the translunar abort constraint allows use of both the Descent Propulsion System (DPS) and the Ascent Propulsion System (APS).[10]

A study to determine the required launch vehicle performance commitment for the J-missions was undertaken in collaboration with both MSFC and MSC. The ground rules for the study were chosen at an informal meeting of Center and Bellcomm personnel. Preliminary data have been sent to MSC for verification of the resulting trajectory requirements.

The performance trade-offs were determined for the spacecraft to assist in understanding the overall effect of the 66-hour lunar surface stay versus the 54-hour stay. The results showed that while the advantage is small, the performance requirements favor the use of a shorter lunar surface stay. For a site such as Hadley in a difficult performance month such as September 1971, the advantage can be about 150 feet per second in additional ΔV availability.

Currently mission performance calculations for site accessibility are done by means of patched conic trajectories at both MSC and Bellcomm. A mission independent allowance for patched conic errors is thus included when determining mission feasibility. Trajectory dependent corrections to patched conic ΔV costs have been determined.[11] These corrections are being implemented into mission feasibility calculations, and in most cases they reduce the required allowance for conic errors below the corrections previously applied.

The profile which is being implemented for the J-missions differs from the current hybrid profile principally in the TLI burn. With the hybrid, TLI places the spacecraft on a nominal free return trajectory after which the SPS is used at TLI + 28 hours to place the spacecraft onto a low perilune trajectory subject to certain abort constraints. The J-mission profile omits the free return segment of the hybrid. The capability of the Reaction Control System (RCS) to establish a safe return to earth for the J-mission profile in the event of certain failures is of interest. For the worst of a sample set of representative J-missions, it was found that the RCS can provide abort

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(10) SPS Requirements for a J2 Tycho Mission, Memorandum for File, M. K. Baker, September 17, 1970.

(11) Corrections to the Patched Conic Calculation of Apollo Trajectories, Memorandum for File, L. P. Gieseler, September 11, 1970.

capability up to eight hours after TLI for the CSM and LM configuration. With the S-IVB attached, the Service Module (SM) RCS can provide capability up to 2.5 hours post TLI. However, using the remaining S-IVB APS propellant and dumping the main-stage propellants would prolong this capability to about ten hours.[12]

A simple graphic means of displaying launch opportunity information was developed to assist NASA management in quick-look assessment of launch opportunity for various landing sites.[13]

Guidance and Navigation

The value of storing a terrain model in the LM computer was studied.[14] This technique will be used for Apollo 14 and subsequent missions.

The efficacy of entry guidance with high inclination orbits was demonstrated.[15] There are some conditions where entry splashdown accuracy is poor, and corrections for these conditions are under study.

Theoretical work on lunar gravity coefficients continued.[16,17] The aim of this project is to compute the coefficients from the shape (and suspected mass concentrations) of the moon. Work was also continued using the Osculating Lunar Elements Program (which computes orbit characteristics from tracking data) to infer gravity coefficients from resulting orbit changes.

The Osculating Lunar Elements Program for orbit determination was shown to have advantages over current Real Time Computer Complex (RTCC) techniques in determining the orbit of the Particles and Fields subsatellite to be put into lunar orbit during Apollo 15.[18] After discussions with MSC, the program was delivered to

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(12) Preliminary Evaluation of SM/RCS Capability to Abort to Earth Entry from the Relaxed Free Return Profile, Memorandum for File, R. J. Stern, September 30, 1970.

(13) Launch Windows-1970 to 1974, Memorandum for File, H. F. Connor, July 7, 1970.

(14) The Effects of Navigation Range Errors when an LGC Lurain Model is Used for Littrow, Memorandum for File, F. LaPiana, July 15, 1970.

(15) Guided Polar Entries, Memorandum for File, S. B. Watson, August 3, 1970.

(16) Transformation of a Potential Function Under Coordinate Translations, TM-70-2014-7, S. L. Levie, Jr., August 13, 1970.

(17) Potential Expansion for a Non-Homogeneous Oblate Spheroid, Memorandum for File, S. L. Levie, Jr., September 29, 1970.

(18) An Analysis of Navigation Performance for the Subsatellite Experiment, Memorandum for File, M. V. Bullock, A. J. Ferrari, July 28, 1970.

them for evaluation of the method. Determination of the attitude of this satellite is important to the Fields experiment. Possible methods for doing this were developed, and a report is in preparation.

MSC requested Bellcomm participation in an independent review of software changes made in the Apollo 14 program. This review is continuing and should be completed in the next quarter. A suggestion that the MSC Software Control Board officially review software anomalies (and their correction) and MIT internally generated coding rearrangements has been approved by MSC.

Performance and Design Requirements

Communication Systems

A study was made of the communication constraints which would result from deletion of the erectable antenna from the Apollo J-missions. It was found that (a) communication to an 85-foot Manned Space Flight Network (MSFN) station would be limited to voice plus low bit rate telemetry when the LM steerable antenna and the low-power mode of the LM transmitter are used, and (b) a 210-foot MSFN station will be required to obtain positive signal margins with the LM Frequency Modulation (FM) modes.[19]

Lunar Surface Operational Capabilities

In a joint effort with NASA, a requirement was identified for a set of common guidelines for use in lunar surface mission planning and related systems performance studies. The scope, objective, data formats and an outline were developed and specific values of system performance parameters were proposed and negotiated with NASA.[20]

A final draft of the Lunar Surface Mission Guidelines was approved by the Apollo Program Office.

A systematic approach to the interdisciplinary problem of traverse design was defined.[21] Nine steps were identified and illustrated in the construction of a sample traverse using a simulated lunar site at Merriam Crater in Arizona. The traverse was documented complete with activities to serve as an aid in the development of crew procedures, in Lunar Roving Vehicle (LRV) evaluation, in crew training, and in traverse demonstrations.

A timeline analysis of the candidate lunar surface staytimes was made to support NASA studies of extending the lunar surface stay to 66 hours. The basic determinant was shown to be a requirement to provide a rest period for the crew just prior to (rather than just after) the critical period comprised of lunar lift-off through rendezvous.

A study was made of the effects of lunar surface staytimes and overall mission duration on orbital science capability considering serial and concurrent operational

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(19) Effects of Deletion of LM Erectable Antenna on LM-MSFN Communications, Memorandum for File, N. W. Schroeder, September 30, 1970.

(20) Establishment of EVA Parameters for Use as Lunar Surface Mission Guidelines, Memorandum for File, P. Benjamin, July 2, 1970.

(21) An Approach to J-Mission Lunar Surface Traverse Design as Illustrated at Merriam Crater, Arizona, Memorandum for File, P. Benjamin, J. C. Slaybaugh, August 4, 1970.

modes for the surface and orbital science periods.[22] It was concluded that the concurrent science mode offers more orbital science time than the comparable serial modes and becomes increasingly attractive as mission durations become shorter and surface staytimes are increased. However, the net science return in the concurrent mode was found to be contingent upon the effects of CSM instrument contamination due to spacecraft effluents and the variations in orbital ground tracks.

Using the various combinations of systems which would be available if Apollo 15 were an H-mission or a J-mission, a preliminary analysis was made of the traverse capabilities at the Hadley-Apennine site.[23] Both walking and riding traverses could be designed to reach the major objectives at the site, with progressively greater scientific return resulting from the increasing hardware capability of the several options available.

A presentation was made to the Apollo Program Director on the status of J-mission surface planning, with emphasis upon the timeline, traverse envelopes, and the development of reference traverses. It was pointed out that the reference traverses average about 40 km total length (versus a considerably greater LRV capability); the last EVA is limited in duration by the water available for cooling instead of by time; and about half of the total time available for traverses is spent in travel.

Lunar Roving Vehicle Studies

Analysis of the dynamic characteristics of the LRV was continued with emphasis on the sliding which can occur during turns. It was shown that little skidding should occur in non-braking and non-accelerating turns at the expected operating speeds.[24]

Consultation with MSFC continued on usage of the stability analysis program delivered to them in the last quarter.

A philosophy for LRV assessment on the moon was developed using the rationale that the primary mission objective is science return, and that engineering tests can be justified only if they lead to a compensating increase in scientific return in subsequent traverse operations. Criteria were identified for differentiating between tests which could increase scientific return and those which are of engineering interest only.[25]

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(22) Effect of Lunar Surface Staytime and Overall Mission Duration of J-Mission Orbital Science Capability, Memorandum for File, G. J. McPherson, Jr., August 13, 1970.

(23) Preliminary Analysis of Traverse Capabilities for a Possible Apollo 15 Mission to Hadley-Apennine, Memorandum for File, P. Benjamin, J. W. Head, July 27, 1970.

(24) Sliding Stability Analysis - Lunar Roving Vehicle, Memorandum for File, S. Kaufman, September 30, 1970.

(25) A Philosophy for LRV Testing on the Moon, Memorandum for File, P. Benjamin, July 17, 1970.

A study of development programs for batteries used in the Apollo, Mariner, Ranger and Surveyor Programs was completed to serve as a baseline for evaluating the confidence level in the LRV battery development program. It was found that the variation in design requirements and the small quantities involved do not permit standardized battery development. In each new program, special attention is needed in requirements definition, manufacturing and quality control, and test programs to minimize battery failures in the field. In accordance with recommendations of the study, NASA conducted a detailed review of the LRV battery development program by a team which included specialists from other space flight programs.

Space Vehicle Systems

Work has continued on evaluation, analysis and modeling of POGO oscillations in the S-II and S-IVB stages.

A finite difference solution for hydrodynamic analysis of a fluid-filled elastic propellant tank was delivered to Bellcomm as the final item of a study performed under subcontract by the Research Institute of Advanced Studies.(26) A computer program for implementing this analysis is near completion.

A stability analysis technique for multi-loop feedback systems was developed for application to multi-engine POGO problems. The technique applies Nyquist stability criteria as each of the multi-loops is opened in sequence.(27)

A preliminary analysis of the POGO stability of the S-IVB was performed(28) and presented to the POGO Working Group. The results compare favorably to flight experience during the second S-IVB burn but are significantly different from first burn experience. The study will be updated when new structural data become available.

In all S-II flights some activity at 11 Hz has been observed near the end of burn. Recently it was suggested that this might be an indication of a potentially serious 11 Hz POGO problem. After examination of the applicable flight and ground test data, it was concluded that the risk of serious levels of 11 Hz oscillation is quite small. A presentation was made to the Apollo Program Office summarizing the S-II POGO situation and recommending that Apollo 14 be flown with no changes specifically for the potential 11 Hz problem.

Examination of flight data from the S-II stage of Apollo 13 during the 16 Hz oscillation showed that the oscillations were reflected prominently in the gimbal actuator

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(26) Longitudinal Vibration Analysis of Partially-Filled Ellipsoidal Tanks by Finite Differences, TR 70-6C, R. L. Goldman, RIAS, August 1970.

(27) Stability Analysis of Lumped-Distribution Feedback Systems Via Open-Loop Nyquist Plots, TM-70-1033-5, G. C. Reis, September 22, 1970.

(28) Preliminary S-IVB POGO Stability Analysis, Memorandum for File, J. J. O'Connor, September 11, 1970.

pressure measurements with no pitch, yaw or roll moments. Significant waveform distortions were observed indicating vehicle non-linearities which are not yet understood.(29)

Work continued on the analysis of the thermophysical aspects of the SM cryogenic oxygen tank. Analysis of past flight data showed results inconsistent with data contained in the current Apollo System Data books.(30)

A study to evaluate the effects on LM payload margins of changes in unusable propellants resulting from movements of the center of gravity was completed.(31) Payload sensitivity factors, expressed in pounds of weight margin per pound of added weight (which changes the center of gravity), were found to vary from 0.7 to 1.4 for the four LM quadrants. If the LRV, at its current weight of 484 pounds, were removed from Quad I, the change in payload margin would be only 300 pounds.

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(29) S-II Engine Actuator Forces During SA-508 POGO, Memorandum for File, L. A. Ferrara, J. J. O'Connor, August 24, 1970.

(30) Flight Performance of Apollo Cryogenic Oxygen System, Memorandum for File, R. V. Sperry, July 13, 1970.

(31) LM Performance Variations from LM Center of Gravity Movement, Memorandum for File, D. M. Duty, September 24, 1970.

Scientific Studies

Site Selection

In preparation for the Apollo 15 site selection, a session on candidate sites was arranged and chaired at a conference on lunar exploration at the Lunar Science Institute, MSC. At the conference a presentation was given on the Marius Hills and candidate highland sites, Descartes and Tycho. The site selection meeting of the geochemistry group at MSC was attended and, in conjunction with MSC, the agenda for the September 24 meeting of the Apollo Site Selection Board (ASSB) was arranged.

In preparation for a decision on a landing site for Apollo 15, studies were made of the capabilities, scientific objectives, and possible traverses at several sites including Marius Hills, Littrow and Hadley-Apennine.[32] Objectives of a mission to Hadley-Apennine include the sampling of Apenninian material and examination and sampling of the rim of the Hadley Rille and associated volcanic deposits.

At the Group for Lunar Exploration Planning (GLEP) meeting on September 21, 1970 a presentation on orbital photography was given which highlighted the need for one high inclination mission and the redundancy of ground track coverage of some of the candidate lunar missions. The Descartes area, a candidate for Apollo 16, was studied to determine landing points which would best serve science activity at this site.

The geologic characteristics of Lade were studied in an attempt to find an additional possible highland Apollo landing site.[33] The area lies in a highland terrain and is characterized by the presence of broad lineations radial to the Imbrium basin.

Apollo 14

A photographic flight plan for the January 31, 1971 launch was proposed. Emphasis was placed largely on the high resolution coverage of the central highlands including the Descartes landing site. Two strips between 35°E and 10°W are to be photographed using the Lunar Topographic Camera (LTC).

The Apollo 14 prime and backup crew members were briefed on lunar landmark recognition and description, and the prime and backup Command Module Pilots were briefed twice on the mission-specific photographic tasks with emphasis on the objectives of bootstrap photography using the LTC.

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(32) Preliminary Analysis of Traverse Capabilities for a Possible Apollo 15 Mission to Hadley-Apennine, Memorandum for File, P. Benjamin, J. W. Head, July 27, 1970.

(33) Geologic Characteristics of Lade, a Possible Apollo Highland Landing Site, Memorandum for File, J. W. Head, July 24, 1970.

Analysis of the results from the Apollo 12 Passive Seismic Experiment (PSE) by the Principal Investigator (G. Latham) has shown a correlation between certain characteristic seismic signals and the moon's perigee. Study of the records of perigee and near-perigee seismic events has led to the suggestion that these signals may originate in the Fra Mauro crater area. A study of the geology of the Fra Mauro region indicated that several potential sources of lunar seismic events exist in the vicinity of the Fra Mauro crater and the Apollo 14 landing site.[(34)] The characteristics and location of these potential sources were identified in the hope that the seismic signals noted during perigee could be correlated with visible transient events which might be correlated with the seismic events.

The suggestion was also made that two Apollo 14 ALSEP experiments, the Cold Cathode Gauge Experiment (CCGE) and the PSE, could be used to test the hypothesis of near-simultaneous seismic and transient gas events.[(35)] A simplified analysis indicated that Neon or lighter gases released near the southern edge of the Fra Mauro crater (the nearest possible source to the proposed Apollo 14 landing point, about 100 km away) would be detected by the CCGE, provided the gas temperature was greater than 250°K. Heavier gases, such as Argon or CO_2, would require a gas temperature of about 300°K to reach this distance. On the basis of the instrument sensitivity, a rate of gas release of at least 2 gm/sec is required in order to be detected by the CCGE. Based on the distribution of potential sources, the suggestion was made that the CCGE be oriented in a southerly or west-to-west northwest direction during ALSEP emplacement on Apollo 14.

Apollo 15

A briefing on orbital science objectives was organized and given to the Apollo 15 Command Module Pilots and the Mission Scientist. Topics included the mission profile, Scientific Instruments Module (SIM) experiments, photographic equipment, and problems of visibility and sun illumination.

The lunar surface coverage for orbital science during concurrent orbital/surface science operation was compared with that obtainable from post-rendezvous orbital science. This was done for the Apollo 15 site, Hadley-Apennine, and for two candidate sites, Copernicus and Marius Hills. It was found that the coverage for concurrent science operation with a 48-hour continuation after LM jettison is greater than that provided by a 72-hour post-rendezvous period. It was also found that the CSM plane change for LM rendezvous has virtually no effect on overall photographic coverage.

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(34) Possible Sources of Seismic and Transient Events in the Fra Mauro Region, Memorandum for File, J. W. Head, September 18, 1970.

(35) Simultaneous Detection of Lunar Seismic and Transient Gas Events, Memorandum for File, G. K. Chang, T. T. J. Yeh, September 18, 1970.

Apollo 16

A briefing on orbital science objectives was organized and given for the Apollo 16 Command Module Pilots and the Mission Scientist. As part of establishing a program for orbital science crew training for Apollo 16, sites were delineated for fly-over exercises to simulate lunar orbital tasks.

Lunar Science Studies

The size-frequency distribution of craters from one thousand meters to tens of meters in diameter was determined for the general areas of the landing sites Fra Mauro and Descartes.(36) It was found that the normalized size-frequency distribution of craters in the Descartes area is comparable to that of the Fra Mauro area, and that the effect of sun elevation on crater counting appears to be negligible if the photographs lack shadows. A fairly accurate count was obtained under stereoscopic conditions even for photographs taken during high sun elevation angles (e.g., 70 degrees).

The Hadley-Apennine area was analyzed to examine the effect of low sun elevation angles on shadowing at landing. The amount of shadowing for sun elevation angles of 15 degrees, 10 degrees and 5 degrees was obtained from a mosaic of Lunar Orbiter photographs taken at about 20 degrees sun elevation.

Recent estimates of the internal electrical conductivity and temperature of the moon are based on the assumption that the response of the moon to discontinuities in the interplanetary field will lead to an increase in the risetime of the discontinuity as observed in the lunar wake. Calculations of the time domain response at the moon show that the response is characterized by a rapid increase with the same time scale as the discontinuity, followed by an overshoot and then a decay.(37) The increase in risetime that is observed thus must be attributed to other effects, and the estimates of the conductivity based on this interpretation should be discounted.

The time domain recordings of the lunar surface magnetic field obtained from the Apollo 12 Lunar Surface Magnetometer were analyzed to provide electrical conductivity information to depths of about 300 km.(38) Assuming a dominant poloidal interaction, models were obtained with conductivities in the range of 3×10^{-3} to 10^{-2} mho/m below 200 km. For a postulated pyroxenite composition of the lunar interior such conductivities correspond to temperatures in the range of 1200 to 1300°K. Other less conductive and cooler models are possible.

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(36) Comparison of Size-Frequency Distribution of Large Craters Around the General Area of Fra Mauro and Descartes Landing Sites, Memorandum for File, V. Hamza, September 28, 1970.

(37) A Comment on Ness's Estimate of the Interior Electrical Conductivity of the Moon, Memorandum for File, W. R. Sill, September 2, 1970.

(38) Electrical Conductivity and Temperature of the Lunar Interior, TM-70-2015-3, W. R. Sill, September 2, 1970.

Soderblom's method for age dating mare surfaces by crater morphology was summarized.[39] By observing the largest unshadowed crater in the 10 m to 1 km diameter range on an Orbiter photograph, and using the figures provided, an area can be dated in a relative sense. An estimate of the absolute ages of the surfaces can be obtained by applying the age data from the Apollo 11 and 12 points and using an assumption about the meteoroid flux history.

Bellcomm participated in the detailed reviews of the surface experiments for the J-missions. As an aid in the evaluation of seismic and traverse gravimeter experiments, the maximum depth of penetration of seismic waves for a specific lunar model and the magnitude of the gravity anomaly expected for semi-realistic geologic models of some of the J-mission landing sites were calculated.

An analysis was made of a proposed experiment to measure the dielectric constant of lunar surface material.[40] The experiment uses measurements of the direct and reflected signal strengths received from the Very High Frequency (VHF) transmitter on the LM by an astronaut walking away from the LM with a signal strength meter. The analysis indicated that perturbing effects, such as antenna patterns and anomalous reflections from the LM structure, may make the measurement uncertainty in the dielectric constant unacceptably large.

Approximately 30 additional geochemistry proposals were evaluated this quarter, and MSC's recommendation on proposal renewals was reviewed.

An evaluation of the present status and proposed extension of the Lunar Ranging Retro-Reflector experiments (a third large array for Apollo 15) was carried out. The results of this analysis were discussed with the Lunar Ranging Experiment (LURE) team of investigators, and their written response was evaluated. The evaluation indicated a clear need for further documentation of the proposal by the LURE team, and a list of open questions was sent to NASA Headquarters.

An investigation was conducted on the results expected from a stack of nuclear emulsions exposed outside the earth's magnetosphere. The expected results were compared and contrasted with the Cosmic Ray Detector Experiment (CRDE) presently assigned to Apollo 15. It was recommended that nuclear emulsions be exposed on the lunar surface on Apollo 16, and that the scientific priority of the experiment be no higher than that of the CRDE.

Lunar Orbital Experiments

Analysis of the multispectral photographs obtained on Apollo 12 continued. Based on computer reduction of more than 30 photographs, no major color differences have been found in the highlands or at the highland-mare boundaries. In order to derive

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(39) Relative Age Determination From Crater Morphology Studies, Memorandum for File, A. F. H. Goetz, August 4, 1970.

(40) Note on the Feasibility of the Dielectric Constant Experiment at Lunar Landing Sites, Memorandum for File, I. I. Rosenblum, September 30, 1970.

relative priorities for processing the remainder of the photographs, a matrix of terrain types, topographic features, and stratigraphic features was compiled in an attempt to show the most likely regions of geochemical differences and their relationship to the photography. Geologic sketch maps were completed for approximately 75% of the photographs as an aid in interpretation and establishing processing priorities. From this data, processing priority lists were compiled. Detailed geologic analysis of several frames showing possible color differences was continued.

Orbital Photography

A parametric study was performed of the effective resolution of the Lunar Topographic Camera (LTC), including the effects of slower shutter speeds and altitude setting errors.(41) In view of the camera's sensitivity to these factors, the study recommended that an analysis be performed for the specific camera selected for the Apollo 14 mission.

The utility of the LTC on J-missions was studied in light of the photographic requirements. The conclusions were reached that this camera would provide 1 meter resolution from the 8x60 nm orbits, 5 meter resolution from the 60x60 nm orbits, and backup capability of the Panoramic Camera in case of malfunction or excessive contamination. It was recommended that the LTC be considered for J-missions.

Recommendations for modifications to the Panoramic Camera included enlarging the field of view of the exposure sensor and mounting it on the rocker arm, providing some Command Module (CM) control of the exposure, and providing CM control to place the camera in monoscopic mode. These recommendations have been approved for implementation.

Efforts on film selection for the terrain camera portion of the Mapping Camera continued. The camera manufacturer has presented data which indicate that film Type 3414 should be used if maximum resolution is the criteria. However, if the Mapping Camera will also be used to provide control for panoramic photography to within 8 degrees of the terminator, then Type 3414 film is not adequate. Consequently, based on this analysis, proceeding with Type 3400 film was recommended for Apollo 15.

A full-scale model of the subsatellite was photographed to simulate photography of the subsatellite immediately after it is ejected from the SIM bay. The experiment showed that the accuracy obtainable from CM cameras was only sufficient to (a) document rough compliance with plan (±10 degrees orientation uncertainty), (b) provide data on certain forms of malfunction (e. g. , non-deployment of booms), and (c) document the deployment (for historic and public information purposes). The data will be evaluated by the Principal Investigators to determine the usefulness of CM photography for determining subsatellite orientation.

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(41) Lunar Topographic Camera Dynamic Resolution, Memorandum for File, H. W. Radin, August 31, 1970.

Earth-Based Optical Observations

A summary of all ground-based observations of Apollo water dumps was prepared.[42] These observations were both photographic and visual (telescopic) and were obtained by a network of professional and amateur astronomers for Apollo missions 9 through 12.

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(42) This was subsequently reported in Summary of Earth-Based Observations of Apollo Water Dumps, Memorandum for File, J. O. Cappellari, Jr., W. I. McLaughlin, October 2, 1970.

Weight Reporting

Skylab Weight and Performance reports for the months of July, August, and September were prepared, summarized for the Skylab Program Director and issued.

Skylab Program Specification

Requirements for experiments M151, M415, M479, M509, S009, S019, S020, S073, S150, T013, T025, and T027 were presented to the Level I Configuration Control Board. These requirements were approved and distributed.

Mission Sequence

A study was conducted to determine the compatibility of planned flight-crew duty cycles with opportunities for earth resources observations of the United States.(43) It was shown that during a 28-day mission launched in July or December 1972, the maximum number of potential opportunities will occur during normal on-board working hours if the crew's sleep periods are scheduled between 11:30 p.m. EST and 7:30 a.m. EST. For a mission launched in July, approximately one out of five opportunities will occur during normal in-flight lunch periods; the comparable figure for a mission launched in December was found to be one out of three. To reduce conflicts between earth observations and high-priority medical experiments, it was recommended that (a) if the launch date is in July, two-man medical experiments be scheduled in the morning during the first week of flight and in the afternoon during the last week, and (b) if the launch date is in December, the same medical experiments be scheduled in the afternoon prior to the ninth mission day and subsequent to the twenty-second mission day.

Consideration was given to types of system failures that might require real time changes in the flight plan.(44) Examples of specific hardware failures were used to illustrate situations in which (a) a mission is terminated early, (b) a revisit mission will be shorter than planned, (c) a mission continues to full term but with reduced crew time available, (d) extra crew time becomes available due to experiment hardware failure, and (e) specific operations must be postponed to a later mission. Real time flight plan revisions must cope with these situations. Response may include a reallocation of crew time to change experiment flight assignments, or even extending the current mission and canceling a revisit.

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(43) Flight Planning for Earth Resources Observations During the First Skylab Mission, Memorandum for File, D. J. Belz, July 27, 1970.

(44) Effects of Spacecraft Systems Failures on Skylab Flight Plans, Addressed Memorandum to W. B. Evans - NASA/MLO, D. J. Belz, August 27, 1970.

Typical crew timelines were developed for a single day of the Skylab-1/Skylab-2 (SL-1/SL-2) mission to serve as a basis for subsystem analyses.(45) In-flight experiments schedules in the timeline included those that require daily crew participation, have large programmatic importance, or illustrate significant types of experiment/spacecraft interactions. Detailed scheduling of early-morning crew activities in the Workshop's Waste Management Compartment illustrated the heavy traffic conditions that will occasionally prevail there - simultaneous two-man or three-man occupancy will be required at times during actual missions to maximize the time available for other assigned crew tasks during the remainder of each day.

The feasibility of scheduling medical experiments within flight crew work periods of 10 hours/day, 6 days/week was investigated.(46) Requirements for several changes to current flight planning guidelines were identified. If Experiment M093 (Vectorcardiogram) is to be performed on each crewman every third day, it will be necessary to schedule crew "days off" six or eight days apart instead of every seventh day, or allow at least one performance of that experiment on days off spaced at seven day intervals. It was also pointed out that during the SL-1/SL-2 mission, some well-lighted passes over the United States will be unavailable for earth resources observations unless medical experiment scheduling constraints are relaxed. The relative phasing of astronaut sleep cycles and spacecraft day/night cycles were shown to affect the time available for manning the Apollo Telescope Mount (ATM) control and display console. It was recommended that flight planning guidelines permit deviations in the start of scheduled sleep periods by as much as plus or minus half an orbital period from the nominal 24-hour cycle.

Flight Mechanics

Descriptions were prepared of four of the powered flight maneuvers which will be performed by the Skylab CSM's in their rendezvous with the orbiting Workshop, and computer routines capable of targeting these maneuvers were developed.(47,48) The routines have been incorporated in a general simulation program called the Navigation and Guidance Simulator.

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(45) Integrated Flight-Crew Timelines for the "Pick a Day" Study, Memorandum for File, D. J. Belz, September 30, 1970.

(46) Scheduling of Three Skylab Medical Experiments, Memorandum for File, B. H. Crane, September 30, 1970.

(47) NAGS Documentation: The NCC/NSR Rendezvous Maneuvers Targeting Routine, Memorandum for File, C. O. Guffee, R. C. Purkey, August 18, 1970.

(48) NAGS Documentation: A Computer Routine for Targeting the NC/NH/NSR Rendezvous Profile, Memorandum for File, C O. Guffee, R. C. Purkey, September 30, 1970.

A separate study of a technique proposed for targeting the first two rendezvous maneuvers (called NC1 and NC2) using the on-board CSM computer concluded that the approximations used in the method are adequate provided that a correction be incorporated to compensate for the difference between true orbits and conic orbits.(49) If the conic correction is not incorporated, the resulting targeting bias errors can result in a significant increase in the distance between the CSM and the Skylab Workshop during the coast period between the second and third maneuvers. On-board measurements are the primary source of navigation information during this period, and in some cases, the increased distance results in a significant decrease (or even entire elimination) of on-board navigation opportunities. In addition, the targeting bias errors, when combined with navigation and execution errors, can have the result that one or more of the subsequent maneuvers will be retrograde (hence, fuel wasting).

The MSFN Unified S-Band (USB) tracking coverage and orbital day/night cycles have been studied for the SL-2 short rendezvous opportunities (Orbit No. M=5, 6, and 7) occurring on the first seven days after the SL-1 launch.(50) Tracking coverage for the SL-2 rendezvous maneuvers is adequate for the short rendezvous; however, the margin for the M=5 coverage to support the first rendezvous maneuver is small enough that the effect of SL-1 and SL-2 launch vehicle dispersions on the tracking coverage should be studied.

A computer program was written to provide an automatic capability to plot data on a Mercator projection map of the earth's continental and island coastlines.(51) Input variables enable the user to select the portion of the earth shown and the desired spacing of latitude and longitude grid lines. The program has proved valuable in displaying earth orbit trajectory and tracking station coverage data on a familiar map projection.

A summary was prepared of the ATM digital computer telemetry formats and the interface between the ATM telemetry system and the auxiliary storage and playback (ASAP) system.(52) The report pointed out that the telemetry system is operated in such a way that it will not be possible to determine in which exact computation cycle various parameters were computed, and it also suggested methods for correcting this problem.

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(49) Study of the MSC Proposed NC1/NC2 Targeting Routine for Skylab Rendezvous, Memorandum for File, C. O. Guffee, R. C. Purkey, September 30, 1970.

(50) Tracking Coverage and Lighting for SL-2 Short Rendezvous, Memorandum for File, W. L. Austin, September 30, 1970.

(51) MKPLOT - A Program for Plotting Data on a Mercator Projection Plot, Memorandum for File, L. K. Hawkins, August 24, 1970.

(52) Skylab ATM Telemetry, ASAP and ATMDC -- How They Work Together, Memorandum for File, D. A. De Graaf, July 15, 1970.

Skylab System Configuration

A study was made of the diffusion characteristics exhibited by the iodine bactericide injected into the potable water tanks in the Workshop.(53) Diffusion was shown to require 9000 days to reach 90% of the equilibrium iodine concentration at the tank wall opposite to the point of injection. In order to overcome this slow diffusion, a means for mixing is now included in the system configuration.

Attitude Control

An evaluation was made of the effects of venting and leakage disturbances on the Skylab attitude control system (ACS). These disturbances produce bias torques which in turn produce Control Moment Gyroscope (CMG) bias momentum that must be dumped.

Operation of the CMG system was evaluated using conservative estimates of the disturbances. Initial results have shown that with three CMG's, operating at 2000 ft-lb-sec each, adequate CMG momentum margin exists for bias momentum dumping by attitude maneuvers alone. With two CMG's operating, the bias momentum also can be dumped using attitude maneuvers alone, but the CMG angular momentum margin is not large. Thus with two CMG's, Thruster Attitude Control System (TACS) propellant may be required for dumping in those orbits in which abnormal venting occurs.

Thermal Control System Studies

The Skylab Orbital Workshop (OWS) thermal model has been generalized to accept transient external absorbed heat input data.(54) The modified model applies the instantaneous heat absorption rates directly to the external surfaces. This method permits the computation of OWS transient temperatures and heat leaks caused by orbital heat flux variations. The thermal model can now simulate thermal missions having both time-varying internal heat loads and orbital heat rates.

The thermal model was used to analyze the OWS Liquid Oxygen (LOX) tank vent line and nozzle temperatures.(55) This analysis showed that the vent penetration through the LOX tank dome, the vent valve, and the colder vent line are all in close proximity to LOX dome surfaces having temperatures of about 20°F at a Beta angle of -30 degrees. Aft skirt temperatures, to which these components are exposed

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(53) Iodine Diffusion in the Skylab Potable Water Tanks, Memorandum for File, J. J. Sakolosky, July 2, 1970.

(54) Generalization of the Skylab Orbital Workshop Thermal Model to Accept Transient External Absorbed Heat Input Data, Memorandum for File, D. P. Woodard, A. W. Zachar, September 28, 1970.

(55) Skylab LOX Tank Vent Lines and Nozzle Temperatures, Memorandum for File, D. P. Woodard, September 21, 1970.

radiatively, will vary from about -40 to -90°F. The lower aft skirt section of the OWS, to which the colder vent nozzle is attached, is likely to reach temperatures below -90°F.

Two computer programs have been developed to extend the thermal analysis of the Skylab to include the X-IOP/Z-LV flight attitude mode required for Earth Resources experiments.(56,57) The programs properly account for the continually changing incident flux and shadowing conditions of this mode.

An analysis was made to determine the diurnal variations of dewpoint temperature within the Skylab vehicle.(58) A range of crew metabolic rates and several possible modes of operation of the thermal control/molecular sieve system were considered. The analysis indicated that with two molecular sieves operating continuously at the 15 pound/hour rate, the dewpoint temperature drops well below 40°F during the crew sleep period when the water generation rate is low. The average dewpoint temperature could be increased by operating a single molecular sieve; however, there would be an appreciable increase in average CO_2 level. Increased average dewpoint temperatures could be achieved by operating a single molecular sieve and bypassing a portion of the airflow around the condensing heat exchangers during the crew sleep period. It was estimated that this approach should satisfy dewpoint temperature requirements over the expected range of crew metabolic rates while increasing the CO_2 level about 20%.

Degradation of Skylab thermal control coatings caused by the SM RCS rocket exhaust was studied.(59) The SM RCS is most damaging to Skylab thermal control surfaces when fired for an extended duration or when fired in a series of several hundred pulses at low engine temperatures. Extended firings overheat the surface while pulse firings deposit contaminants, most likely monomethyl hydrazine nitrate. The Skylab surface area most susceptible to degradation by the rocket exhaust is the SM RCS sun-side door which requires a solar absorptance below 0.6 to maintain propellant tank temperature. With possible concentrated plume impingement, as well as other degradation sources, an end-of-mission solar absorptance of 0.5 is expected with the baseline Skylab mission.

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(56) The Orientation Geometry of General Spacecraft Surface Elements and Solar Vectors, Memorandum for File, J. W. Powers, September 21, 1970.

(57) Cluster Shadowing of the Skylab Orbital Workshop, Memorandum for File, A. W. Zachar, September 28, 1970.

(58) The Influence of Thermal Control System Operation and Environmental Parameters on the Skylab Atmospheric Dewpoint Temperatures, Memorandum for File, D. G. Miller, September 25, 1970.

(59) A Review of Thermal Control Coating Degradation by the Service Module Reaction Control System Rocket Exhaust and Estimated Effects on Skylab, TM-70-1022-12, G. M. Yanizeski, September 21, 1970.

Structures and Dynamics

A dynamics model of the OWS was updated to represent current mass properties, and the structural modal data were summarized.(60) A general computer program incorporating modal synthesis was developed. A unique feature of the program is its ability to handle large dynamic systems (up to 850 degrees of freedom) efficiently.(61)

The present SL-1 wind constraints were reviewed. It was shown that the Apollo in-flight winds criteria are not appropriate for Skylab, and recommendations were made for modification of the ground winds criteria.(62, 63)

Communication Studies

A description of the communication systems for the SL-1, SL-2, SL-3 and SL-4 missions was prepared.(64) The systems include those for the crew, the Saturn IB and Saturn V Launch Vehicles, the CSM, the Workshop and the ATM and reflect the system designs that were current as of June 1970.

The status of the color television distribution system planned for the Skylab Workshop was reviewed.(65) The use of Apollo type television cameras in the Skylab revealed some incompatibilities that are being eliminated.

The feasibility of using the speaker assembly of a speaker/intercom unit as a microphone to pick up conferences among the crewmen in the wardroom for real time transmission to the ground or for on-board recording was examined.(66) It was concluded that such use was not practicable because of the low acoustic signal to noise ratio that would exist. More feasible alternatives were discussed.

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(60) This was subsequently reported in Updated Orbital Workshop Structural Modal Analysis, Memorandum for File, H. E. Stephens, October 6, 1970

(61) Multi-Segment Modal Synthesis for Large Dynamic Systems, Memorandum for File, S. N. Hou, September 30, 1970.

(62) Skylab 1 Inflight Wind Constraints, Memorandum for File, R. E. Hunter, July 20, 1970.

(63) Skylab Ground Winds Criteria, Memorandum for File, R. K. McFarland, September 30, 1970.

(64) Description of the Communications Systems of Space Vehicle for Skylab Missions SL-1 through SL-4, TM-70-2034-8, A. G. Weygand, August 6, 1970.

(65) Status of the Design of the Color Television Distribution System of the SWS of the Skylab Program, Memorandum for File, A. G. Weygand, September 16, 1970.

(66) Voice Communications On-Board Skylab A, Memorandum for File, A. G. Weygand, July 2, 1970.

The communications coverage and data handling by the MSFN for a typical day in the first Skylab mission were analyzed.(67) The MSFN as presently configured plus a new station in South America could support quite adequately the Skylab activity assumed for the typical day. About 3.6 x 10^9 bits of data would be transmitted by the orbital assembly, and all of it would be received by the MSFN.

Gravity Substitute Workbench

Three analyses were completed on Experiment M507 (Gravity Substitute Workbench). One of these dealt with the effect of rigid body vehicle dynamics on the minimum force required to retain an item on the surface of the workbench.(68) The analysis indicated that for those vehicle accelerations that are predictable, i.e., TAC's thruster firings and CMG targeting, an object will remain on the workbench surface if the artificial gravity field is 10^{-4} g's or greater.

A second study computed the drag force on metallic objects produced by the aerodynamic workbench configuration.(69) The computation indicates that the force exerted amounts to one percent or less of the force of gravity acting on similar bodies at the surface of the earth. Only a flat disk-shaped body would experience a sizable acceleration, on the order of 0.2 g, provided its flat surface remained oriented normal to the air stream. While these force levels exceed the minimum level required to overcome the effects of vehicle dynamics mentioned above, further work is required to evaluate the effects of vibration and the effect of the low force levels on an unrestrained object above the working surface.

An analysis of the Electrostatic Workbench(70) concluded that the present configuration does not provide an effective gravity substitute. In the steady state no long-range electrostatic forces act in the working space above the surface of the bench, and during the transient period following switch-on of the device, the forces exercised are extremely weak. The device actually operates as a "sticky" surface due to short range surface forces and not as a gravity field simulator.

Skylab B Studies

Configuration studies of Skylab B in support of the artificial gravity experiment option were continued. One of the studies dealt with the application of torque using

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(67) Skylab Communications Coverage and Data Handling for the "Pick-a-Day" Study, Memorandum for File, J. E. Johnson, September 4, 1970.

(68) Required Artificial G Field for the Skylab Gravity Substitute Workbench, Memorandum for File, W. W. Hough, September 30, 1970.

(69) The Aerodynamic Gravity Substitute Workbench for Skylab, Memorandum for File, M. Liwshitz, T. T. J. Yeh, September 25, 1970.

(70) The Electrostatic Workbench - A Gravity Substitute (Skylab Proposal M-507), Memorandum for File, W. R. Sill, September 25, 1970.

the CSM RCS thrusters to establish, control, or remove angular momentum. Thruster firing times were optimized such that any specific angular impulse can be applied with a minimum expenditure of fuel. Analytic solutions for the optimum conditions were obtained in closed form.(71) The results, while not limited to Skylab B maneuvers, were used in simulations of the rigid body dynamics of the spin-up maneuver.(72) The total optimum firing times were divided into an equal number of segments and the thrusters operated in a repetitive pulsed mode such that the average torque was applied about an assumed axis of maximum moment of inertia. Because the instantaneous torque is never about the correct axis, spacecraft wobble is induced. Wobble is a small variation of the angular velocity superimposed on the desired steady rotation. A particular sequence of pulsed thruster firings, chosen to minimize the absolute value of off-axis components of applied angular impulse, resulted in acceptable amplitudes of wobble, even when there was substantial error in the knowledge of the location of the axis of maximum moment of inertia. Another sequence, symmetric in time about specific points, reduced the wobble by a factor of five for the case where the location of the axis of maximum moment of inertia is known precisely. This sequence is therefore superior to the non-symmetric sequence.(73)

The phenomenon known as wobble may arise from improper thrusting, venting, leakage or crew motion. The characteristics of the Skylab motion in the wobble state were described in both inertial and vehicle coordinates.(74) A parameter, designated the excess energy ratio, was suggested for use in characterizing the wobble state. This parameter is superior to wobble angles as a measure of the wobble state as it is invariant in time, while wobble angles generally vary with time.

One means of damping wobble energy utilizes the CMG system on the Skylab. A preliminary study of the effectiveness of this method was undertaken.(75) Control torques provided by CMG's were assumed proportional to spacecraft angular velocity components perpendicular to its spin axis. This control law was found to damp wobble energy but resulted in accumulated CMG angular momentum. A trade-off was shown to exist between the wobble decay time and CMG momentum accumulation.

In assessing the control requirements for minimizing wobble energy, it is necessary to establish wobble limits. One limit is of physiological origin. Since wobble is

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(71) Minimization of SM RCS Fuel for Skylab Attitude Manuevers, TM-70-1022-13, W. W. Hough, L. D. Nelson, August 3, 1970.

(72) Spin-up of Skylab B for Artificial Gravity, TM-70-1022-14, L. E. Voelker, September 30, 1970.

(73) An Improved Thruster Firing Sequence for Spin-Up of Skylab B for Artificial Gravity, Memorandum for File, L. E. Voelker, September 30, 1970.

(74) Skylab Wobble State in an Artificial Gravity Experiment, Memorandum for File, G. M. Anderson, August 18, 1970.

(75) Wobble Damping of Spinning Satellites Using CMG's with Application to a Skylab B Artificial-G, TM-70-1022-16, R. A. Wenglarz, August 28, 1970.

a state of variable angular velocity, its presence can be sensed by the semi-circular canal system of the inner ear. Threshold limits for Skylab B wobble were estimated using ground based test data. (76) Although these limits are not considered absolute because of uncertainty in the data base, the limits are believed conservative since tolerance levels are much greater than perception thresholds.

Two studies examined means for reducing system cost for maintaining the spin vector pointed toward the sun - a requirement arising from the use of solar arrays for electrical power. Gravity-gradient torque and the apparent annual solar motion are the principal effects acting to disturb the desired pointing.

One study determined the maximum deviation from true solar pointing in a thirty day period without active control but where the timing of the experiment period is optimized. (77) The uncontrolled motion results in a maximum power loss of 2.2%. This loss is in contrast to a requirement for 450 pounds of RCS fuel to maintain exact solar pointing.

Another alternative to thrusting for pointing control utilizes magnetically derived torque. (78) In this method, current in coils on the Skylab interact with the earth's magnetic field and produce a torque on the vehicle. Averaged over the orbit any required moment may be applied. A pointing control law was formulated that uses sun sensor outputs to determine the magnetic moment to be developed by a main coil whose magnetic moment profile over the orbit approximates the profile requiring minimum electric energy from the power source. Small vernier coils along the other two vehicle axes are used to correct for misalignment between the main coil and the spin axis and to provide for bias moment dumping when flying in the solar inertial attitude.

The magnetic control system requires additions to the Skylab attitude control system amplifiers to control the current to the main and vernier coils, a magnetometer to measure the earth's magnetic field, and some computer capability. With an estimated 1700 watts available during the most demanding orbit of a selected 30 day experiment period, the magnetic system could be designed to weigh about 1450 pounds.

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(76) Physiological Limits on Skylab B Wobble During an Artificial Gravity Experiment, Memorandum for File, R. J. Ravera, September 30, 1970.

(77) Uncontrolled Motion of a Spinning Spacecraft, TM-70-1022-15, R. J. Ravera, September 3, 1970.

(78) Use of Magnetic Torque for Pointing Control of a Spinning Skylab, TM-70-1022-17, W. Levidow, September 10, 1970.

MISSION OPERATIONS STUDIES

Several configurations of MSFN sites and communication relay satellites were examined to determine their ability to relay bulk experiment data from the proposed Skylab B mission.(79) This method of transmitting experiment data to the MSFN could reduce by approximately 500 pounds the amount of film and magnetic tape that would need to be brought back by the CSM.

The impact of the MSFN station reliability on the minimum number of MSFN stations needed for Skylab support was examined.(80) Using reliability data for Apollo missions as analyzed by the Applied Physics Laboratory/Johns Hopkins University for GSFC, it appears probable that support by MSFN stations that provide unique coverage will be lost for one or two orbits during a 56-day Skylab mission.

During the Apollo 13 countdown and launch, voice communications between the KSC test personnel and the spacecraft were monitored.(81) A few anomalies were noted such as voice distortion on one channel and low voice signal levels from Mission Control Center (MCC), but the support provided was generally satisfactory. The problems remaining are mainly in the communication interfaces.

The acquisition time for first order phase lock loops was analytically determined for the case in which the input to the loop is a sine wave and Gaussian noise.(82) It was shown that the mean acquisition time and the mean time to cycle slip increase as the signal to noise ratio in the loop increases.

A study was made of the performance characteristics of alternative communication satellite modulation techniques in a multipath environment representative of the case in which the satellite approaches the horizon of a transmitting or receiving station.(83)

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(79) Transmission of Bulk Experiment Data from Skylab to the MSFN, TM-70-2034-7, R. K. Chen, H. Kraus, J. P. Maloy, July 2, 1970.

(80) Manned Space Flight Network Station Reliability Considerations for Skylab Support, Memorandum for File, B. F. O'Brien, September 30, 1970.

(81) Voice Communications Observations During Countdown and Launch of Apollo 13, Memorandum for File, L. A. Ferrara, J. T. Raleigh, September 30, 1970.

(82) Acquisition Time in a First Order Phase Lock Loop, TM-70-2034-6, L. Schuchman, July 10, 1970.

(83) A Review of Modulation Techniques for Use in a Satellite Multipath Environment, TM-70-2034-9, L. Schuchman, September 30, 1970.

Characteristics of the Space Ground Link Subsystem (SGLS) developed and used by the Air Force Satellite Control Facility were reviewed and compared with the NASA Unified S-Band System (USBS).(84) Both are coherent systems, and both make use of a modification of the JPL Mark I ranging system. Although there is similarity in services offered, there are significant differences in the frequency bands of the up-links and in the subcarriers used in the down-links. To establish compatibility such that one system could command the other would require substantial changes in equipment.

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(84) Space Ground Link Subsystem (SGLS) Characteristics, Memorandum for File, J. H. Fox, August 18, 1970.

ADVANCED MANNED MISSIONS SYSTEMS ENGINEERING

Manned Space Flight Experiments Program Studies

Task Order No. 36

Skylab B Experiments Program Rationale

Four candidate experiments for a Skylab B payload were described to indicate how astronauts could be used to greater advantage.[85] Using an electron gamma-ray experiment as one example, typical tasks were described which would use a range of astronaut capabilities in the conduct of the scientific experiment. Measures of in-flight task performance were suggested which could provide a planning base for the design and conduct of post-Skylab B experiments.

A stellar ATM operating in association with a second Skylab was studied.[86] Manned support of telescope servicing and the effect on operating modes were discussed. It was postulated that engineering studies and valuable scientific experiments could be accomplished with a stellar ATM on Skylab B. Engineering data would be applicable to the development of telescopes operating either in a free flying mode or attached to a Space Station.

Impact of Space Shuttle on Experiment Programs

The unmanned satellite program of Option III of the 1969 report to the Space Task Group was examined to define areas of potential impact of the Space Shuttle. Following a presentation to the Advanced Manned Missions Office of NASA Headquarters, a memorandum on this subject was published.[87] The Shuttle, with suitable upper stages, was found to be capable of delivering all the satellites and recovering all but the interplanetary payloads. Alternative design concepts for two large, facility class satellites, the Orbiting Astronomical Observatory (OAO) and the High Energy Astronomical Observatory (HEAO), illustrate that the design of this class satellite for a launch-and-recovery mode is potentially advantageous. An alternative design concept for Nimbus illustrates a possible design for orbital servicing.

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(85) Skylab B Experiment Program Rationale, Memorandum for File, A. C. Buffalano, W. B. Thompson, September 1, 1970.

(86) A Stellar ATM for Skylab B, Memorandum for File, M. H. Skeer, D. B. Wood, July 29, 1970.

(87) Impact of the Space Shuttle on Satellite Payloads, TM-70-1011-6, H. B. Bosch, P. L. Chandeysson, L. Kaufman, A. S. Kiersarsky, D. Macchia, W. B. Thompson, F. F. Tomblin, July 24, 1970.

A concept for a manned experiment module to be carried in the Shuttle bay was examined. With an experiments program patterned on the NASA Airborne-Research Program, this concept appears worthy of future study.

Advanced Technology

Task Order No. 37

A preliminary study was undertaken to examine the feasibility of achieving low recurring costs with expendable boosters using liquid oxygen/liquid hydrogen (LO_2/LH_2) propellants. This study was supported by parametric sizing calculations.(88) It appears that a two-stage minimum-cost-design LO_2/LH_2 booster can be competitive with three-stage, earth-storable propellant pressure fed concepts.

A performance comparison was made of chemical, nuclear solid core, and nuclear gas core propulsion stages to determine the missions for which each concept might be suitable. The results showed that for lunar orbit delivery payloads of less than 20,000 pounds, a chemical propulsion stage would require less propellant than either nuclear stage.(89) For payloads in the range between 20,000 and 130,000 pounds, a nuclear solid core is better than or equal to a gas core stage. For missions requiring greater payload and/or higher velocities (notably manned planetary missions), the gaseous core nuclear rocket would give better performance.

The heaviest and least reliable components of advanced solar power systems for spacecraft have been the batteries used for nighttime power. Analysis of flywheels as energy storage devices indicates that the resultant power system can have a total weight as low as 144 lbs/kw which is less than 20% of the weight of any other space power system in the range of 0 - 250 kw.(90)

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(88) A Parametric Study of a Two Stage, High Mass Fraction, High I_{sp} Expendable Launch Vehicle, Memorandum for File, J. J. Schoch, July 7, 1970.

(89) Comparison of Advanced Propulsion Stages, Memorandum for File, C. S. Rall, August 12, 1970.

(90) Solar Cell - Flywheel Energy Storage Power System, TM-70-1012-3, R. Gorman, September 15, 1970.

Environmental Studies

Task Order No. 38

Radio Interferometeric Studies of Other Planets

Reduction of radio interferometer data for Mercury, Venus, Mars, Jupiter and Saturn, obtained at the National Radio Astronomy Observatory during four sessions in 1969 was continued this quarter. The reduction is now at such a stage that instrument calibration is completed, and all the data are in a final form with necessary corrections made.

Programs for data display were developed. For Venus, programs for data analysis are nearly completed. The data are being examined to establish the microwave opacity of the atmosphere, the dielectric constant of the surface rock, the surface temperature and pressure, and the magnitude of the possible surface temperature variations - all within narrower or much narrower limits than previously measured.

The Jupiter data were examined in a preliminary manner. The results are significant in indicating very close centering and symmetry for Juptier's radiation belts (in contradiction to an earlier hypothesis).

Effect of Thermal Radiation on Atmospheric Circulation of Venus

A study on the effect of thermal radiation on a general circulation model of the Venus atmosphere is underway. On the basis of a grey gas approximation, a parametric study was performed for various values of optical thickness and Boltzmann number. The results indicate that, for optical thickness of order unity and small Boltzmann number, the wind velocity may be substantially increased as compared with the convective case without radiation.

Distribution of Asteroids in the Asteroidal Belt

A study was completed on the distribution of asteroids in the asteroidal belt. Using a stochastic model of asteroidal collisions, a unique steady state solution was derived for the distribution of asteroidal masses which is valid for a long peroid of time after creation. The observed distribution of asteroids agrees with this steady state solution; therefore, (a) it does not seem possible to estimate the age and initial form of the asteroidal distribution, and (b) a reasonable and unique physical basis has been provided for the estimation of the distribution of asteroids too small to be observed.

Manned Space Flight Program Analysis

A phased development of the shuttle booster and orbiter could result in lower annual expenditures during development than simultaneous development of both. Were the phased approach taken, there are several arguments that support development of the orbiter first and to follow with the booster.(91) Such an approach would also remove the uncertainty of the orbiter actual weight when development of the booster began. This would eliminate the need to oversize the booster to compensate for uncertainty in the orbiter weight, required if the two were developed simultaneously or the booster first.

An analysis was also conducted to see if a low cost launch vehicle, originally intended for a bulbous payload shape, could accommodate, as an interim operating mode, a lifting body shaped payload.(92) Results indicate that booster payload penalties in the range of 1% can be expected for pressure fed vehicles. For this class of vehicles, tank pressure is the critical factor in the design of the tank walls; hence only the interstage structure must be modified. The analysis assumed that the trajectory could be shaped to reduce wind loads on the payload.

A computer program was written to permit rapid rough sizing of various candidate Shuttle configurations.(93) The program analyzes two-stage vehicles considering the variation in specific impulse with altitude and the effects of vehicle size on mass fraction. Given the total mission ΔV's, the program will (a) size a two-stage vehicle for a range of ΔV splits, (b) define the ΔV split required to produce minimum gross weight or equal size stages, and (c) define the payload capability and performance sensitivities for a given launch vehicle. The program is currently in use supporting a transportation system sizing study.

The interaction of the Space Tug with other Integrated Program hardware was investigated to gain an appreciation of the relative merits of possible operational modes: (a) ground based, utilizing either the Space Shuttle only, or the Shuttle and the Tug; and (b) space based, utilizing the Tug at the Space Station.(94) The study indicates

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(91) Effect of Space Shuttle Booster First vs Orbiter First Development on Booster Contingency Oversizing, Memorandum for File, D.E. Cassidy, August 11, 1970.

(92) The Increase in Structural Weight of a Low Cost Expendable Booster Due to a Lifting Body Payload as Compared to a Bulbous Payload, Memorandum for File, W.H. Eilertson, C.E. Johnson, September 17, 1970.

(93) Computer Program for Launch Vehicle Sizing and Sensitivities, Memorandum for File, A.E. Marks, July 7, 1970.

(94) Space Tug Operational Requirements for Satellite Placement, Revisit and Retrieval, Memorandum for File, M. H. Skeer, July 29, 1970.

that selection of operational modes has significant effects on the design configuration. Acceptance of complex modes can enable considerable reduction in Tug size and simplification of design.

A survey was conducted of some recent studies of the collision hazard between a manned space station and other space objects.[95] In spite of different collision models and different assumptions concerning the distribution of orbits, the results of these studies are similar. The statistical predictions indicate that, for each 100 missions of ten years duration in a 55°/500 km (270 nm) circular orbit, a Space Station can expect to experience two to four collisions with other objects in orbit. These predictions represent an upper bound and do not assume any collision avoidance maneuvers.

Payload performance of nuclear and chemical lunar Shuttles were compared including the effects of earth-moon transfer time, plane change maneuvers, one-way missions, two-stage Shuttles, and aerobraked return to earth orbit.[96] For large payload requirements, around 120,000 pounds to lunar orbit, the nuclear Shuttle is lighter even if the chemical Shuttle is staged or aerobraked. Higher velocity missions and higher payloads tend to further increase the advantage of the nuclear Shuttle. However, lower payloads diminish the performance advantage of the nuclear Shuttle, and for payloads of 50,000 pounds or less, staged chemical Shuttles become competitive.

To further evaluate lunar logistics operations, a study was conducted to find circular earth orbits that are synchronized to allow passage over the launch site at least once every several days and to allow frequent zero-plane-change transfers to a specified lunar polar orbit.[97] The analysis revealed 40 orbits which have altitudes less than 300 nm, lunar orbit opportunities at least once every six months, and passage over the launch site at least once every three days. Typical orbits that are attractive from the point of view of Shuttle logistics support and orbital lifetimes are 258 nm/31.8°, 204 nm/36.2°, and 177 nm/38.1°. These orbits allow bimonthly lunar mission opportunities and passage over the launch site at intervals of one, three and two days respectively.

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(95) A Survey of the Orbital Collision Hazard for a Manned Space Station, Memorandum for File, H. B. Bosch, September 4, 1970.

(96) Performance Comparison of Nuclear and Chemical Lunar Shuttles, Memorandum for File, D. J. Osias, August 14, 1970.

(97) Synchronized Earth Parking Orbits for Zero-Plane-Change Transfer Between Earth's Surface and Polar Lunar Orbits, Memorandum for File, C. S. Rall, September 18, 1970.

Post Apollo Manned Lunar Program

A study was performed which produced a sample manned lunar exploration program for the 1980's based on the Integrated Plan but reflecting a more careful look at scientific objectives, safety requirements, and logistics support. (98) The scientific program involves field trips of two weeks duration with extended mobility. Safety considerations lead to a lunar orbiting depot and medical station, a LM-B on lunar orbit, and a LM-B lifeboat carried on cislunar Shuttle flights. Logistics analysis identified a preferred, "moon-synchronous" earth departure orbit permitting monthly logistics trips to a station in a polar lunar orbit. The study concluded that there is no purely scientific requirement for the orbital base since proposed functions can be achieved otherwise. Similarly, there seems to be no operational need for a "base" in earth departure orbit, although the cislunar Shuttle should be stored there between trips. It was noted that unmanned probes of the moon's gravitational field are necessary before the stability of lunar polar orbits can be determined.

Planetary Exploration

The utility of a reusable Mars excursion module (MEM) which is refueled in Mars orbit was evaluated. (99) It was concluded that reusable vehicles would most likely be practical only in association with low circular parking orbits, and that the propellant weight alone for each round trip to the surface of a reusable MEM would be several times the entire weight of an expendable MEM. Reusable vehicles would therefore be justified only if recurring hardware costs of nonreusable vehicles overshadowed the transportation costs and higher development cost associated with a reusable MEM.

To minimize overall mission ΔV's, orbital precession can be utilized to bring a parking orbit (which is initially aligned with a given arrival trajectory) into alignment with a desired departure trajectory at the end of a specified time interval. For planetary missions with long staytimes, this technique can eliminate the velocity requirements for effecting the orientation change between arrival and departure directions. A study has shown that the actual hyperbolic excess velocity vector will deviate from the nominal one depending on the accuracy to which the mass parameter (μ) and oblateness parameter (σ) are known. (100) The relative uncertainties in these parameters for Mars are $d\mu/\mu = 4.67 \times 10^{-6}$ and $d\sigma/\sigma = 2.29 \times 10^{-3}$. For a 1986 Mars conjunction mission with a 580 day staytime, the velocity penalties associated with these uncertainties range between 40 and 365 fps. The corresponding contingency propellant requirements are approximately 0.3% and 3% of the total weight of the orbiting spacecraft.

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(98) Post Apollo Manned Lunar Program, Memorandum for File, E. M. Grenning, E.D. Marion, J.E. Nahra, G.T. Orrok, W.R. Sill, September 30, 1970.

(99) Comparison of Reusable and Non-Reusable Mars Excursion Modules for Multiple Landing Missions, Memorandum for File, M.H. Skeer, August 11, 1970.

(100) Sensitivity of Planetary Parking Orbits to Uncertainties in the Mass and Oblateness Parameters, Memorandum for File, H.B. Bosch, August 12, 1970.

Scientific Studies

Fluorescence stimulated by solar photo-ionization in the earth's upper atmosphere was studied.(101) Fluxes of up to 10^5 photons/cm^2 sec sterodians are generated by K-α emissions of nitrogen and oxygen at 100 km. It was concluded that this flux may place a significant limitation on low energy (.1-1 keV) x-ray astronomy experiments that are performed during the daytime at altitudes below 300 km.

A simple numerical method for the computation of three-dimensional supersonic flows was described.(102) The simplicity of the approach results from the use of a finite difference scheme that does not require a shock fitting procedure but permits a direct integration of the equations of motion in the axial direction. Application to non-symmetric (at an angle-of-attack) conical flows was presented and compared with other solutions of the same problem and experimental data. The limitations of the technique were discussed, and a direction for further development of this approach was indicated.

The results of a geophysical study of a terrestrial cryptoexplosion structure were published.(103) Cryptoexplosion structures are crater-like geologic disturbances whose origins are unknown (both meteorite impact and volcanic or steam gas release theories receiving equal support). Since it is thought that the method of formation may have been similar to the method of formation of some of the craters on the Moon and on Mars, an understanding of their origin would allow us to plan astrogeologic investigations by astronauts more efficiently. Magnetic and gravitational surveys led to the conclusion that the structure studied was related to the tectonics of the region and, therefore, was probably caused by an endogenous force.

Objectives and procedures for the Tektite II aeromicrobiology experiment were reviewed.(104) It was noted that interpretation of the experiment data may be influenced by the air mixing patterns present in the Habitat. Results of a General Electric test of the air distribution system suggest that the mixing is much greater than the theoretical prediction. An experimental program was proposed to resolve this discrepancy.

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(101) Atmospheric X-Ray Fluorescence, TM-70-1011-5, F.F. Tomblin, July 7, 1970.

(102) Computation of Three-Dimensional Supersonic Flows with Shock Waves, TM-70-1011-7, I.O. Bohachevsky, August 6, 1970.

(103) The Geophysical Signature Associated with a Cryptoexplosion Structure, Memorandum for File, J.H. Fox, July 10, 1970.

(104) Tektite II - Aeromicrobiology Experiment and the Environmental Control System, Memorandum for File, L.D. Sortland, June 30, 1970.

Procedures involved in the data management/handling program for Tektite II behavioral data were described. [105]

Computer Studies

Current experiment data handling activities were examined to help in formulating a philosophy for Space Station experiment data handling. [106] Data rates and mission durations in the Space Station era are capable of producing much more data than available scientists and engineers could assimilate. Data compression and data selection are suggested as methods for constraining the data to a manageable amount.

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(105) Tektite II Data Management/Handling. Memorandum for File. M. R. Reynolds. September 28, 1970.

(106) Experiment Data Handling and Analysis on Future Space Missions. Memorandum for File. R. J. Pauly, August 14, 1970.

SPECIAL TASK ENGINEERING STUDIES

Analysis of Haze Effects on Martian Surface Imagery

Task Order No. 35

The Bellcomm members of the Mariner Mars '71 Photo-Interpretation Team have continued to support the planning effort for this mission. A study has been made of a possible contingency mission which could be undertaken in the event of the failure of one spacecraft before the other has been inserted into orbit.(107) The proposed contingency orbit is a modified Mission B orbit having a period of ~9/8 of the Martian day. In addition to the repeated "high sun" photography required for the study of seasonal albedo changes, contiguous mapping photography may be acquired near periapsis. Other photography sequences for meteorological and geodetic studies can also be accommodated. The inclination of the contingency orbit is increased from the 50 degrees of Mission B to 60 degrees in order that satisfactory observations may be made of the southern polar region.

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(107) Mariner Mars '71 Contingency Mission - A Preliminary Study, Memorandum for File, G.A. Briggs, August 27, 1970.

ENGINEERING SUPPORT

Computing Facility

Most of the computer programs at Bellcomm are written in the Fortran language, and these programs perform their Input/Output operations using a set of subroutines called the FORTRAN I/O library. These subroutines have been rewritten at Bellcomm in order to obtain greater efficiency from the computer and mass storage device.[108] It is estimated that the throughput of the Univac 1108 has been increased 33% by the use of the new library.

The Univac 1108 computer operations were continued under the EXEC 8 multi-programming system. During the period from July 1 to September 30, NASA Headquarters' usage of the Univac 1108 computer was 13,624 charge units. Total usage of the computer during the quarter was 744,810 charge units.

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(108) BCMIO - The Bellcomm Exec 8 FORTRAN I/O Library, TM-70-1031-2, W.M. Keese, September 15, 1970.

LIST OF REPORTS AND MEMORANDA

(List in Order of Report Date)

This index includes technical reports and memoranda reported during this period covering particular technical studies.

The memoranda were intended for internal use. Thus, they do not necessarily represent the considered judgment of Bellcomm which is reflected in the published Bellcomm Technical Reports.

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Computer Program for Launch Vehicle Sizing and Sensitivities, Memorandum for File, A. E. Marks	July 7, 1970
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W. R. Lucas - PD-DIR
G. F. McDonough - S&E-DIR
W. A. Mrazek - PD-DIR
E. F. M. Rees - DIR
F. A. Speer - PM-MO-MGR
W. Teir - PM-DIR
J. W. Thomas - PM-SL-EI
H. K. Weidner - S&E-DIR